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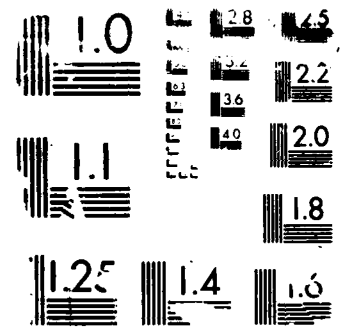
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THE EVALUATION AND SELECTION OF A FIFTH GROUND ANTENNA SITE FOR THE GLOBAL POSITIONING SYSTEM

THESIS

TERY L. DONELSON
CAPTAIN, USAF

AFIT/GSO/ENS/87D-4

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THE EVALUATION AND SELECTION OF A FIFTH GROUND ANTENNA SITE FOR THE GLOBAL POSITIONING SYSTEM

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements of the Degree of

Master of Science in Space Operations

Tery L. Donelson, B.S.

Captain, USAF

December 7, 1987

Preface

The purpose of study was to provide a method for evaluating the performance capability of a fifth ground antenna in conjunction with the current Global Positioning System ground control network.

The extensive testing and evaluating of the methodology resulted in a smooth system for evaluating numerous site locations. Further study should be continued, as this method could be incorporated with economic, political, and geographic analysis to provide the most ideal location for a fifth ground antenna.

In performing the evaluation and writing of this thesis I have had a great deal of help from others. I am extremely grateful to my faculty advisor, Major Bruce Morlan, for his continuing patience and assistance in my times of need. I also wish to thank my other thesis committee member, Lt Col Jim Robinson, for his insight on the aspects of my study. I want to thank Mr. Russell P. Bone and Mr. Donald M. McDowell of the Joint Service System Management Office for the GPS NAVSTAR. If not for their help in acquiring data, and the sponsorship of this thesis by their organization, I would not have completed this study. Finally, I wish to thank my wife Cecelia for her understanding and concern for my efforts as everything seemed to be collapsing around me.

Tery L. Donelson

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Abstract

The purpose of this was to provide a method for evaluating the performance capability of a fifth ground antenna in conjunction with the current Global Positioning System ground control network.

Using the SATVIEW program module from the Satellite Analysis Program Library, a data file of satellite contact periods of 24 satellites for 96 ground locations was produced. After various calculations of this data, a single measure of merit was produced for each location and used to rank the 96 site locations.

The study found the best site location was located at 60 degrees south latitude and 100 degrees west longitude.

The measure of merit was determined by combining the performance capability of each site with its mission availability probability over 16 different scenarios. The final results indicated that the best region for selection was between Australia and South America and north of the Antartic.

Using the performance results of this study, further study should be conducted to include economic, political and geographic factors into the evaluation process.

THE EVALUATION AND SELECTION OF A FIFTH GROUND ANTENNA SITE FOR THE GLOBAL POSITIONING SYSTEM

I. Introduction

Background

The NAVSTAR Global Positioning System (GPS) is a space based radio navigation system being developed to provide accurate position, velocity and time any place on or near the earth, 24 hours of every day, and under all weather conditions. The GPS performance characteristics provide significant benefits in the areas of spacecraft navigation, satellite delivery, equipment positioning, resource mapping, payload deployment and retrieval, propellant economies, data processing, and mission planning (13:204). GPS is a passive radio system and is comprised of space, control, and user segments.

The space segment consists of 18 navigational satellites in six orbital planes, plus three operational spares. The three in-orbit spares will be positioned in such a way as to provide optimum coverage of the continental United States. A satellite failure in one of the three planes containing a spare will result in the spare being moved to a position close to the failed satellite. A failure in one of the other planes will cause satellites in adjacent orbital planes to be moved within their planes to provide the best possible coverage until a new satellite can be launched(6:1). The satellites will maintain 12 hour orbits at an altitude of approximately 20,200km. The satellite spacing will provide a minimum of four satellites in view of the user at any time, insuring three-dimensional data and accurate time.

The ground control segment manages the entire satellite ephemeris, creates the navigation message file, determines nominal commanding requirements, schedules space vehicle (SV) contacts, and monitors the SV state-of-health. It maintains configuration and control of the SV and ground system hardware and software, identifies failure mechanisms, and commands SV reconfiguration in response to real-time anomalies (14:62). The control segment consists of six monitor stations, one master control station, and four ground antenna upload stations. The monitor stations track the orbits of the satellite and the navigation signals broadcast by each satellite. The master control station processes the information accumulated by the monitor stations, notes the discrepancies or errors in the navigation signals, and produces messages to correct these discrepancies. The ground antennas receive commands from the master control station and relay the commands to the SVs for correction on orbit (1:26). At least once a day each satellite receives its data from the upload station. The satellite stores this information and continuously transmits it in a composite dual code signal on two different frequencies designated L1 and L2 (11:4).

The user segment is the collection of all user sets and their support equipment. The user set receives and processes the satellite navigation signals, converting them to orthogonal position coordinates and velocity vectors and accurate user clock drift and offset bias terms. User equipment will range from relatively simple and lightweight manpack-type receivers to sophisticated receiver/processors designed for accurate performance in highly dynamic environments (13:205). Because the satellites continually transmit navigation data without being commanded by the user, the system is passive and can serve unlimited users provided they have receivers (14:38).

The GPS navigation concept involves the accurate and continuous knowledge of the distance from each satellite in view to the user. Four satellites are required to resolve the navigation position problem of position in X, Y, Z, and time. The four satellites having the best geometry can be selected manually or automatically by the user receivers using ephemeris data transmitted by the satellites (11:5).

Problem Statement and Justification

The accuracy provided by the GPS is not a question for debate, accuracies on the order of ten meters may be anticipated (8:3). However, from the standpoint of reliability and continuous, uninterrupted service, the case is not so clear. The present 18 satellite GPS constellation provides four satellites in view at all times, but the loss of a satellite will result in a reduced capability to furnish the required navigational information. One of the major alternatives available is to add satellites until the point is reached that the system could sustain the loss of one satellite without causing outages to receivers (6:11).

With a 24 satellite constellation there would be six or more satellites in view about 99% of the time. That is, the locations where only four or five satellites would be visible would be few (6:5).

The additional satellites would require additional contacts by the control segment. The current control segment needs to be evaluated to determine if the four ground antennas can effectively accommodate the additional contact requirements. The Joint Service Systems Management Office (JSSMO) for the NAVSTAR Global Positioning System, at Warner-Robins AFB, Ga. has requested an analysis of the location of a possible fifth ground antenna for the ground control segment (3).

Research Problem

Will a fifth ground antenna be needed to effectively provide control information to the 24 satellite constellation? If a fifth ground antenna were necessary, where should it be located?

Scope

The need for a fifth ground antenna can be determined by evaluating the performance of the current four ground antennas against a 24 satellite constellation. Although there are various possible configurations for a 24 satellite constellation, the constellation consisting of three orbital planes of eight satellites each will be used for this study. This constellation represents the original satellite configuration for the

Global Positioning System, prior to its reduction to the current 21 satellite configuration, and is a probable configution for any future increase. The comparison of the two constellations will be based on the difference in contact capability of the four ground antennas and the possible effect the added workload might present to the control segment. This study will not be concerned with the added workload on the master control station and the monitor station, although they could be evaluated using similar methods. The Satellite Analysis Program (SAP) will be used as the primary tool to provide the data necessary for the analysis.

The location of the fifth ground antenna is determined by the performance capability of the ground control segment during losses of 0, 1, or 2 of the original ground antenna. The performance capability is measured in conjunction with the mission availability of the sites to produce a single number of merit for each of the evaluated sites.

Assumptions

The following assumptions are made to simplify the handling of the problem:

1. Any orbital perturbations associated with the satellite constellations are handled by the Satellite Analysis Program.

2. The locations tested will be based on latitude and longitude increments. To search for land masses across the globe would be beyond the time constraints of this study.

3. The orbital elements used for the 24 satellite constellation are viable, though partially theoretical, estimates based on strong symmetry argument.

4. The ground control network never loses more than two ground antennas at one time. The probability of the network losing three or more antennas at one time is less than one per cent.

Presentation

The study addresses the capability of the control segment ground antennas to provide adequate service to a 24 satellite GPS constellation and the search for a suitable location for a fifth antenna. Chapter 2 contains the literature review accomplished for this study. Chapter 3 contains a description of the Satellite Analysis Program Library used to provide the data for the decisions made in the study. Chapter 4 contains a discussion of the approach used to determine the ground antennas' performance and the results obtained in the performance comparison. Chapter 5 contains an analysis of the 96 ground locations and the criteria used for the evaluation. Chapter 6 contains a summary of the conclusions of the study.

II. Literature Review

The 21 Satellite Configuration

The 21 satellite configuration represents the current GPS constellation proposal. It consists of six orbital planes containing three SVs each and three operational spares. The following data was provided by the NAVSTAR GPS JSSMO for use on this project (7):

```
orbital period          -- 11 hours, 57.2608 minutes.
eccentricity            -- 0.
inclination             -- 55.0 degrees.
argumnent of perigee    -- 0.0 degrees.
right ascension of
the ascending node      -- see Table 2-1.
mean anomaly            -- see Table 2-1.
epoch element time      -- 1 July 1985, 0000 hrs GMT.
```

This information provided all the necessary elements for the analysis of the 21 satellite system by the Satellite Analysis Program.

The 24 Satellite Configuration

The selected configuration is based on the original requirements of the initial 24 satellite GPS constellation. The configuration consisted of three orbital planes of eight satellites each and was characterized by the following elements (4:175, 10:31, 8:3):

```
orbital period          -- 12 hours.
eccentricity            -- 0.
inclination             -- 63.0 degrees.
```

The other elements required for the constellation were not found. Consequently the following elements were chosen to complete the element set:

argument of perigee	-- 0.0 degrees.
right ascension of the ascending node	-- see Table 2-2.
mean anomaly	-- see Table 2-2.
epoch element time	-- 1 July 1985, 0000 hrs GMT.

The argument of perigee was chosen as 0 degrees because of the circular orbits of the satellites (4:175). With a circular orbit, it is easy to model the center of the earth as the center of the orbit and assume all points on the orbit are equal distance from the center. By definition, it follows the argument of perigee could be any position on the orbit, thus to keep the numbers simple, 0 degrees was chosen.

The three orbital planes were originally offset from one another by 120 degrees in longitude (10:31). The choice of 30, 150, and 270 degrees for the right ascension of the ascending node was arbitrarily chosen based on this information.

The ideal spacing of the satellites within an orbital plane requires equal spacing (6:11). For eight satellites in a single orbit this is 45 degrees. The best overall performance for a 24 satellite constellation, in terms of satellite visibility, is attained when the phasing between adjacent orbital planes is 15 degrees (6:11). The choice of the starting position for satellite A1 was arbitrary and the subsequent satellite initializations were made based on the A1 position.

Since the constellation was arbitrarily configured, the epoch element time is completely random. The time was chosen for simplicity as it was already available to the Satellite Analysis Program from the 21 satellite constellation data.

21 SATELLITE CONSTELLATION

GPS SATELLITE	RT ASC OF THE ASCENDING NODE	MEAN ANOMALY
A1	30 DEG	137 DEG
A2		257
A3		17
A4(SPARE)		167
B1	90	177
B2		297
B3		57
C1	150	217
C2		337
C3		97
C4(SPARE)		307
D1	210	257
D2		17
D3		137
E1	270	297
E2		57
E3		177
E4(SPARE)		87
F1	330	337
F2		97
F3		217

Table 2-1 Orbital Locations for the 21 Satellite Constellation (7).

24 SATELLITE CONSTELLATION

GPS SATELLITE	RT ASC OF THE ASCENDING NODE	MEAN ANOMALY
A1	30 DEG	0 DEG
A2		45
A3		90
A4		135
A5		180
A6		225
A7		270
A8		315
B1	150	15
B2		60
B3		105
B4		150
B5		195
B6		240
B7		285
B8		330
C1	270	30
C2		75
C3		120
C4		165
C5		210
C6		255
C7		300
C8		345

Table 2-2 Orbital Locations of the 24 Satellite Constellation.

Although the elements of the 24 satellite configuration are not as "accurate" as the elements of the 21 satellite configuration, the constellation is feasibly sound and can accurately be used for this study. If, at a later time, completely factual elements can be obtained, this study could be completed in the same manner, using the same methods.

The Ground Antenna Upload Station

The four ground antennas for the GPS control segment are located at Cape Canaveral, Diego Garcia, Ascension Island, and Kwajalein Island. The Upload Stations operate under the control of the master control station and control and consist of the equipment and computer programs required to transmit command and navigation messages received from the master control station to the satellites and to receive satellite telemetry data for forwarding to the master control station (12:12).

A space vehicle (SV) must be within the line of sight of a ground antenna to receive commands transmitted by the ground control segment. The availability for commanding a SV is determined by the amount of time the SV remains in station coverage above the minimum elevation. A five degree minimum elevation for SV commanding was established to reduce atmospheric distortions and signal propagation (14:73).

Contact Requirements

Based on the performance of the phase I SVs, it has been determined that the navigation data must be uplinked to the SV at least once every 24 hours to maintain the 16 meter accuracy

(14:87). Given no uplink commanding is accomplished over a period of time, it appears the accuracy of the system degrades gracefully. Accuracy would degrade almost linearly from the nominal 16 meters to 180 meters after seven days and further degrade to 400 meters after 14 days if uplink commanding is not accomplished (14:143).

A system specification report by the IBM Corporation indicated the navigational upload shall be generated for each operational SV, a minimum of three times per day (12:26). A requirement was also mentioned that the Operational Control Segment shall be designed to support a SV Telemetry, Tracking, and Command contact at least every eight hours for each operational SV (12:31).

In this study, three contacts per day are assumed required for each SV.

Duration of Contact by the Ground Antenna

All SVs must receive navigation data to perform their mission. The data consists of frequency standard (clock) corrections, ionospheric propagation delay model coefficients for single channel users, ephemeris data for that specific user, almanac data (less accurate ephemeris data) for the other SVs in the constellation, special message data, and age-of-data ephemeris word (14:86).

The uploading could be accomplished in 64 seconds. However, the SV verifies reception of good data by transmitting a verification word after each block of data is received. This usually increases the total uplinking time to approximately three minutes (14:90).

The original Joint Program Office for GPS specified that the uplink time per SV should not exceed seven minutes (14:90). For the purpose of this study, an uplink time of five minutes will be used. Consequently, any SV contact by a ground antenna less than five minutes will not be considered within this study.

III. The Satellite Analysis Program Library

Overview

The Satellite Analysis Program (SAP) Library is a collection of computer codes designed to assist a space systems analyst with commonly encountered problems. The intent is to provide a "tool box" of routines that enable the analyst to easily calculate such things as ground traces, sensor coverage, and ASAT system performances (9:1). The SAP Library consists of 17 stand-alone program modules.

SATVIEW

SATVIEW is a program model from the SAP Library that determines the ability of a system of sensors to view a system of satellites. The sensors can be ground-based and/or space-based. For each sensor, the program calculates viewing periods of the target satellites over an input observation time. A view period is defined as the time between acquisition (entrance into the sensor field-of-view) and the loss-of-signal (exit from the field-of-view) (9:2.13).

The SATVIEW module is used to calculate the periods when one or more of the GPS satellites are in view of a ground antenna. The antennas are specified by their location in terms of altitude, longtitude and latitude, and by their field-of-view and boresight direction. The boresight is described by an azimuth and elevation angle. The minimum elevation angle at which the ground antenna can operate can also be specified (9:1.27).

The SATVIEW model allows for the use of Keplerian trajectories and non-Keplerian trajectories of the orbiting body. Non-Keplerian motion of an orbiting body includes perturbations caused by the non-spherical nature of the earth's gravitational field, as well as the effects of atmospheric drag. The gravitational perturbations lead to secular precessions of the ascending node and the argument of perigee and to periodic variations in the orbital motion (9:1.20). Since the non-Keplerian trajectories present a more realistic representation of actual events, the study was completed using the necessary orbital elements for these trajectories within the SATVIEW module. The elements required were the element epoch time, the right ascension of the ascending node, the inclination, the argument of perigee, the mean anomaly, the eccentricity and the mean motion.

The output data from the SATVIEW program required editing for this study. SATVIEW is designed to evaluate one ground control network per computer run. The output data contains a title page, a review of the input data, listings of the view periods for each ground sensor (by satellite), bar graph representations of these view periods, bar graph representations of the view periods of each satellite (by sensor), and bar graphs representing the number of sensor contacts per satellite and the percentage of contact time for each sensor.

The evaluation of the 96 locations individually with the four current antennas is not practical due to the time requirements of each run. Running SATVIEW against 16 ground locations at a time provides the raw data required for this study after six computer runs. The total output is then edited to a data file that contains only the view period information for each ground antennas against each satellite.

IV. Ground Antenna Capability Analysis

Model

The SATVIEW program was run for a period of 168 hours to allow both constellations to orbit the earth 14 times and to provide for multiple contacts by the ground antennas. The search was restricted to contacts of a minimum of five minutes at an elevation above the five degree minimum. The geographic locations for the four antennas are as follows (M):

SITE	LONGITUDE	LATITUDE
KWAJALEIN	167.482 E	9.399 N
DIEGO GARCIA	75.450 E	7.400 S
CAPE CANAVERAL	80.922 W	28.483 N
ASCENSION	14.400 W	7.900 S

The 21 satellite configuration is evaluated first to achieve a standard for comparison. It is assumed that the level of service provided by the four ground antennas for the 21 satellites is a reasonable standard because this is the actual system that is proposed.

Analysis

The SATVIEW program provides the periods of view by each ground antenna for each satellite. The program also determines the periods that a particular satellite is viewed by the entire system (all four antennas). A summary of this information is provided in Table 4-1. From the data, it can be determined that the longest period of time that a satellite is out of view of the total ground network is approximately

21 SATELLITE CONSTELLATION

SV	% IN VIEW OF GA	SV	% IN VIEW OF GA
A1	92	D1	99
A2	99	D2	93
A3	93	D3	92
A4	92	E1	93
B1	100	E2	92
B2	93	E3	100
B3	93	E4	94
C1	92	F1	94
C2	95	F2	100
C3	100	F3	92
C4	93		

Table 4-1 Percentage of Time a SV is in View of any Ground Antenna.

24 SATELLITE CONSTELLATION

SV	% IN VIEW OF GA	SV	% IN VIEW OF GA
A1	92	B5	89
A2	92	B6	90
A3	89	B7	93
A4	91	B8	96
A5	93	C1	92
A6	95	C2	95
A7	88	C3	91
A8	90	C4	89
B1	89	C5	90
B2	89	C6	92
B3	91	C7	90
B4	93	C8	90

Table 4-2 Percentage of Time a SV is in View of any Ground Antenna.

323 minutes (8% of the total run time). This event occurs for six of the satellites (A1, A4, C1, D3, E2, and F3). This low percentage for loss of contact time can be assumed to be acceptable because it reflects the current GPS constellation.

To determine if the four ground antennas can efficiently cope with the added workload associated with the augmented 24 satellite constellation, three evaluations were completed.

First, the 24 satellite constellation was evaluated against the SATVIEW program. The period that a particular satellite was in view of any ground antenna represented the primary data. A summary of this information is provided in Table 4-2. From this data, it is observed that the shortest period a satellite is in view of at least one ground antenna is 88% of the time. Since this percentage is less than the comparison percentage of the 21 satellite constellation (92%), the evaluation by itself is not enough to make a determination.

Second, the capability of the control network is evaluated using the worst case scenario for satellite contacts. The peak workload for the ground control segment occurs when transmissions are required to four different SVs simultaneously (12:30). Since one ground antenna can contact only one SV at a time, the worst scheduling scenario would occur if all the SVs were within the same contact period. From Table 4-2, the satellite A7 represents the SV with the lowest period of contact during the week. Using the lowest contact percentage, the allowable time for contacts would be 3548.16 minutes.

$$(88\%) \times (1 \text{ week}) = .88 \text{ weeks} = 3548.16 \text{ minutes}$$

There are 24 satellites, each requires three 5-minute contacts per day over a period of one week (7 days).

(24 SVs) x (3 contacts/day) x (5 min/contact) x (7 days) =
2520 minutes for the total constellation

The total requirement of 2520 minutes of contact for the week is easily handled by the worse case availability of the SVs for the period of 3548 minutes.

Third, the system is evaluated using the maximum allowable time for a contact, by specification, of seven minutes.

(24 SVs) x (3 contacts/day) x (7 min/contact) x (7 days) =
3528 minutes

This final test showed that if the contacts are still made within the set standards, the current ground antennas can cope with the augmentation of the satellite system.

Conclusion

Though the evaluations only tested the availability of the ground antennas to contact the SVs, the analysis showed they would be able to accommodate the augmented system. The third test implied only a twenty minute allowance would be available if all events conspired against the system. The evaluation also showed that while the system was capable of performing its assigned task, there will be very little room for stressing the system. Many events could quickly apply stress to the system. A satellite could develop poor state-of-health and require almost constant uplinking or at a minimum additional contacts. Situations could present themselves around the world that require more updates to be applied to the satellites. Also, the equipment could fail at a control site, removing the ground antenna from the operational control segment for hours or days. The ground antennas should be augmented with the satellite constellation to allow for the handling of possible stress to the system.

V. Methodology and Evaluation

Introduction

This chapter provides the information on the methods for determining the sites for consideration and the duration of the simulation run used to obtain the necessary data for performing the selection. The methodology used to evaluate the performance and mission availability of each location is presented and a step-by-step example of the eval- uation of one site is also provided.

Location Selections

The evaluation of every possible location on the globe is beyond the scope of this study. The locations used in this study represent points selected within the boundaries of the GPS constellation ground traces. Points are not eliminated from evaluation because of political, geographical, or economic reasons. These factors can be considered after the preliminary evaluation that is represented by this study. The points within the ground trace boundaries are selected to uniformly cover the surface of the globe under the ground traces of the satellites.

The orbital plane of a satellite remains fixed while the earth turns under the orbit. The net effect of the earths' rotation is to displace the ground track westward on each successive revolution of the satellite. Instead of retracing the same ground track over and over, a satellite eventually covers a swath around the earth between the latitudes north and south of the equator equal to the inclination (2:142). The inclination of the GPS satellite is 63 degrees. This means the satellites will not pass directly over any ground antenna above a northern latitude of 63 degrees or below a southern latitude of 63 degrees. The best location for a ground antenna would be on the equator side of these two latitudes because the antenna performance is evaluated by the time the satellite remains within the field-of-view (FOV) of the antenna. The FOV time is greater at locations that allow the satellite to at least reach the latitude of the ground antenna. For the purpose of this study, the upper and lower latitude bounds are 60 degrees north and 60 degrees south, respectively.

The selection of the specific locations for consideration is determined by choosing points of equal distance from each other within the previously determined boundaries. The initial point of measurement is 0 degrees latitude and 0 degrees longitude. A measure of 20 degrees is chosen as the increment because it is small enough to allow for a comprehensive search, but large enough as not to require excessove numbers of computer simulation runs.

The incrementing of the latitude from 60 degrees south to 60 degrees north is straightforward and results in locations at seven different latitudes. The incrementing by longitude is not as simple. The incrementing around the equator by 20 degrees results in 18 evenly spaced locations. Moving north and south by 20 degrees, and keeping to the criteria of equal distance, results in only 16 evenly spaced locations. This is the result of the lines of longitude becoming closer together as the latitudes approach the poles. Another 20 degrees results in 14 evenly spaced locations and, finally, at 60 degrees north (south) latitude the result is nine evenly spaced locations. Figure 5-1 represents the locations as they would appear on a near mercator projection. The locations appear in the projection to have a greater distance between them as they approach the poles. Figure 5-2 represents the actual positions of the same points as they are projected on an equal area projection of the globe and verifies that the locations are evenly spaced. This spacing results in 96 possible ground sites for evaluation. Each site name, with its actual latitude and longitude, is listed in Appendix A.

Each location is evaluated at the most optimum altitude, sea level. Due to the restriction of the angle of elevation (five degrees above the horizon), the lower the altitude of the ground antenna, the longer the satellite will remain in the FOV. If this study was being conducted using actual sites rather than sample latitudes and longitudes, then the actual altitude of the specific location could be used.

Simulation Duration

The Satellite Analysis Program allows for the duration of the analysis to be determined by the user. To determine the length of the simulation for the SATVIEW program, two items had to be considered. First, does the duration of the simulation run impact on the results obtained? Second, is there

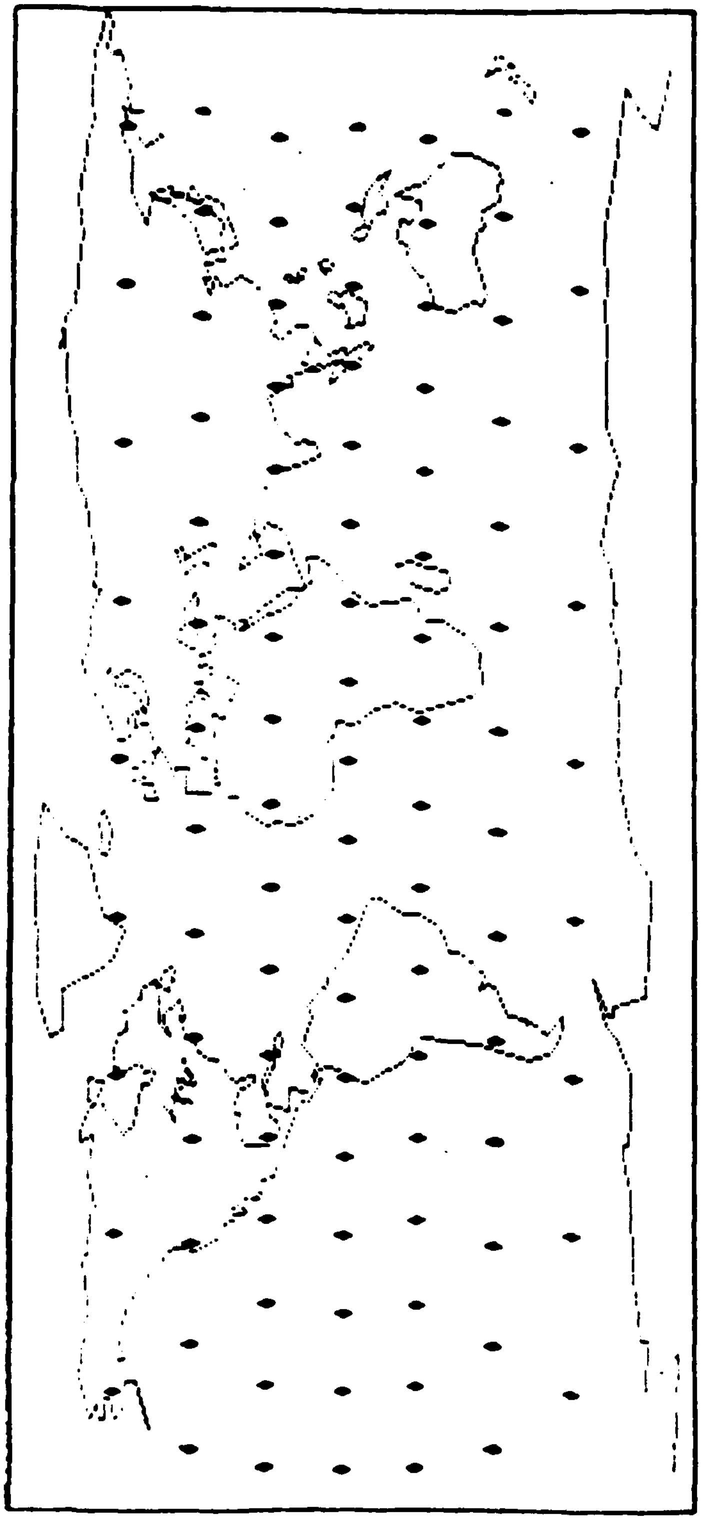

Figure 5-1. The 96 Site Locations on a Near Mercator Projection of the Globe.

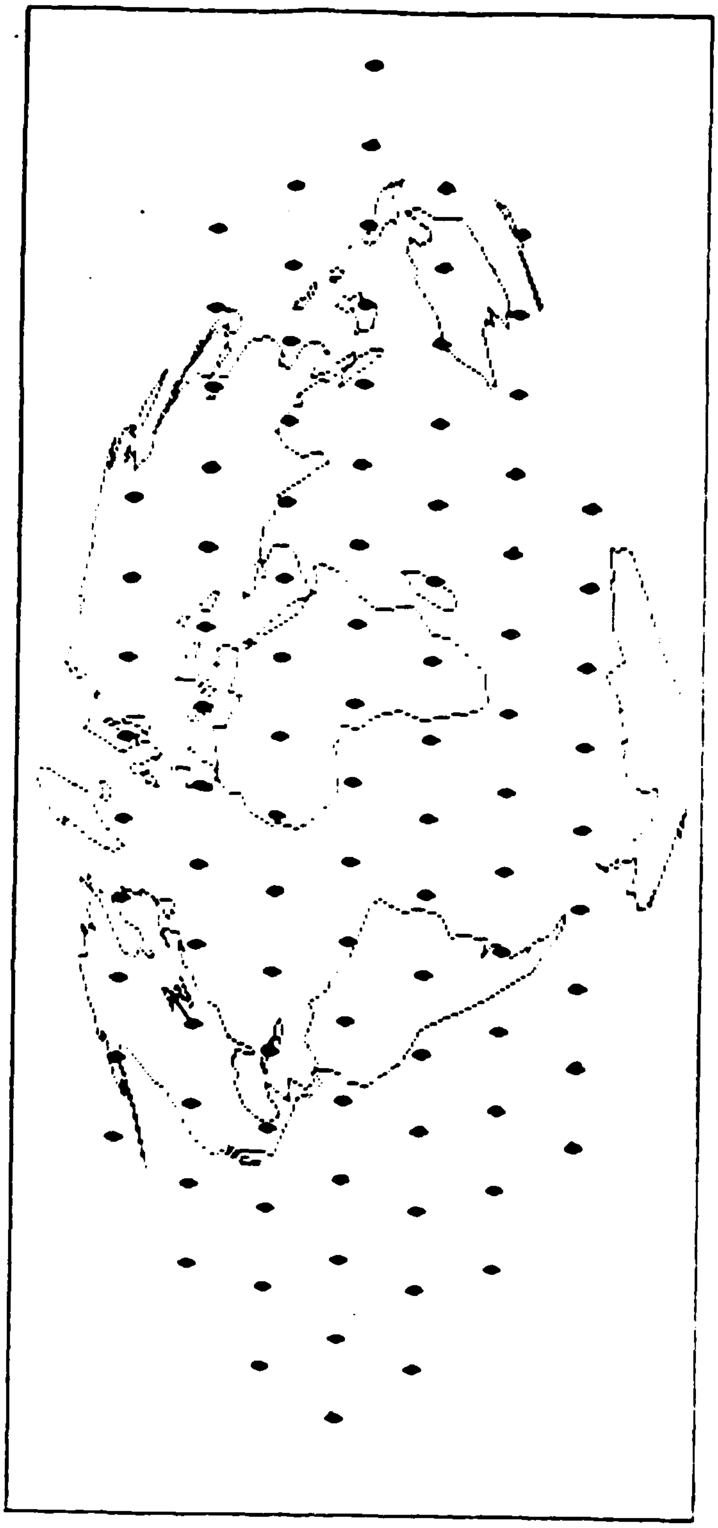

Figure 5-2. The 96 Site Locations on a Equal Area Projection of the Globe.

a measurable difference in the data obtained from running the simulation at different starting times but with the same duration? An initial sensitivity analysis is performed to determine the impact of these factors.

The contact requirements for a GPS satellite indicate three contacts must be performed in a 24 hour period (12:26). To ensure the data from the SATVIEW program at least covers this requirement, 24 hours is determined to be the lower limit for any simulation run. To evaluate the run time durations, the 24 satellite and four ground antenna configuration is simulated using SATVIEW for 24, 48, and 168 hour periods. The periods were started at various times throughout 1985 and 1986.

The measure of effectiveness for the analysis consists of the percentage of the time the constellation is available for contact by a ground antenna. This percentage is determined by taking the mean of the percentages of the time each satellite is in view of any of the ground antennas. Table 5-1 gives an example of the information obtained from the 24 hour simulation run that began at 0000 hrs on September 1, 1985. The average for this simulation run is 92.8%. Subsequent runs for periods of 48 hours and 168 hours resulted in averages of 92.7% and 92.4% respectively. The difference between the 24 hour result and the 168 hour result is approximately 40 minutes (.4% over a 168 hour period). This difference is not considered significant enough to justify the many extras hours of computer time that would be required to evaluate each of the 96 locations over a 168 hour period. If the analysis is used for only a couple of locations, then the duration of the simulation runs should be extended. For the purpose of this study, the duration of all simulation runs is 24 hours.

SV	%	SV	%	SV	%
A1	93	B1	93	C1	91
A2	95	B2	91	C2	92
A3	97	B3	92	C3	93
A4	90	B4	95	C4	92
A5	91	B5	97	C5	91
A6	92	B6	93	C6	94
A7	93	B7	91	C7	95
A8	90	B8	92	C8	95

Table 5-1. Percentage of Time each Satellite is in the Field-of-View of at Least One Ground Antenna.

With the duration determined at 24 hours, it is necessary to evaluate the effect of the starting time of the simulation on the measure of performance. To accomplish this, the SATVIEW program was run during seven different time periods of 24 hours each. An example of the actual results, for the September 1, 1985 test run,are displayed in Table 5-1. A summary of the seven runs can be found in Table 5-2.

The result from the July 1, 1985 run provides the largest deviation from the mean. This is due to the bias introduced by the initial start-up time of the simulation also being July 1, 1985. The other six runs were done with the system running and removed any bias associated with the initial start-up. The results indicate that, although the percentage for each satellite would differ over any 24 hour period, the performance percentage for the entire constellation will remain fairly constant. This result can be attributed to the symmetry of the GPS satellite configuration. For the purpose of this study, the simulation run start time of 0000 hrs on July 8, 1985 is used. This time allowed for the initialization bias to be reduced and it remained close enough to the constellation start-up time (epoch time) as to not require an extended period of time to reach the simulation start point.

RUN	PERFORMANCE %
JULY 1, 1985	92.92
JULY 3, 1985	92.83
AUG 1, 1985	92.79
SEPT 1, 1985	92.83
OCT 1, 1985	92.79
NOV 1, 1985	92.83
JULY 1, 1986	92.83
MEAN	92.831

Table 5-2. Summary of 24 Hour Simulation Runs

Ground Antenna Evaluation

The evaluation of the 96 site locations is accomplished by producing a measure of merit for each location and selecting the location with the highest measure. The single number for each location is determined by the performance of the site during various situations and the probability that the situation exists.

The situations being evaluated arise from the fifth antenna performing with 0, 1, and 2 ground antennas being non-operational. This results in evaluating the performance of the ground site in 16 different situations. The situations involving more than two ground antennas being non-operational are not evaluated here because they represent less than a 1% probability of occurrence. Table 5-3 accurately displays the 16 situations.

1

Non-operational Sites (NOS)

		1	2	3	4	5
	1	2	3	5	8	12
	2	*	4	6	9	13
NOS	3	*	*	7	10	14
	4	*	*	*	11	15
	5	*	*	*	*	16

1. Kwajalein
2. Ascension
3. Diego Garcia
4. Cape Canaveral
5. Fifth Location

Table 5-3. Matrix of 16 Situations.

Each box represents a different situation. For example, box 3 represents the situation of Kwajalein (row 1) and Ascension (column 2) being non-operational. Box 7 represents the situation of only Diego Garcia (row 3, column 3) being non-operational. Box 1 is not part of the non-operational matrix and represents the situation of all five ground antennas being operational. The matrix is symmetrical about the diagonal and the lower triangle is not used.

Another factor affecting the performance of each proposed site is the mission availability of each ground antenna. Mission availability is defined as the availability of the site to the operators to perform the operational mission. Several factors affect mission availability; broken equipment, loss of communication links, power outages, scheduled maintenance, training, and testing. The following mission availability probabilities are used for the four ground antennas (5):

1.	Kwajalein	.9629
2.	Ascension	.9134
3.	Diego Garcia	.8754
4.	Cape Canaveral	.7880

The mission availability of the fifth antenna is estimated from the probabilities of Kwajalein, Ascension, and Diego Garcia. The Cape Canaveral probability is not included because the Cape Canaveral ground antenna is subject to greater periods of training and testing than would be expected of the fifth antenna and its inclusion could bias the probability. The evaluation is done using the three following probabilities for the fifth site:

1. .9172 (the mean)
2. .9629 (the maximum)
3. .8754 (the minimum)

These mission availabiliy numbers are used to determine the probability of each of the 16 situations occurring. For example, the likelihood of the situation represented by box 3 occurring is .00203. Box 3 represents the situation of both Kwajalein and Ascension being non-operational and the others being operational.

Probability(Box 3) = (1-.9629)*(1-.9134)*.8754*.788*.9172

The probability that Kwajalein is non-operational is represented by (1-.9629) and Ascension by (1-.9134). The probabilities for each of the 16 situations is displayed in Table 5-4.

SITUATION BOX	MISSION AVAILABILITY
1	.55647
2	.02144
3	.00203
4	.05276
5	.00305
6	.00751
7	.07920
8	.00577
9	.01419
10	.02131
11	.14971
12	.00194
13	.00476
14	.00715
15	.01351
16	.05023

Table 5-4. Mission Availability Probabilities for the 16 Situations(Calculated Using .9172 for the Fifth Antenna).

The next step in the process is to evaluate the performance of each site in each situation. How does the selected site perform with the three remaining operational sites? As previously calculated (see Chapter 4), the performance is based on the percentage of the time the 24 satellite constellation averages in the FOV of at least one of the ground antennas. The computer program used to calculate these numbers for the 96 locations is listed in Appendix B. This process is repeated for each location until all 16 situations are evaluated. Table 5-5 represents the situation matrix for site S60E180. Each box contains the performance percentage for S60E180 and the particular situation. The values of each box for all 96 locations is listed in Appendix C.

!.990074!		NOS				
		1	2	3	4	5
	1	.910859	.874652	.777748	.757436	.780469
	2	*	.953876	.782956	.731133	.836690
NOS	3	*	*	.902777	.814467	.777749
	4	*	*	*	.901764	.820949
	5	*	*	*	*	.929456

Table 5-5. Situation Matrix for Site S60E180.

It should be noted that column five of the situation matrix is the same for all 96 locations because it represents the situations of the fifth ground antenna being non-operational.

The final step in the process to determine the measure of merit for the 96 locations involves the summing of the products of the performance percentage and the mission availability probability of each situation box. Continuing to use site S60E180 as an example, box 3 on the final situation matrix is equal to .00177.

Final (box 3) = (.874652) * (.00203)

The final situation matrix for site S60E180 is shown in Table 5-6. The summation of the 16 products results in a measure of merit of .93828 for site S60E180. The computer code used to generate the final measure of merit for all the locations is listed in Appendix D. Appendix E contains the complete list of all 96 locations, and their measures of merit, in descending order, for each of the three (average, high, low) availabilities assumed for the fifth site.

!.550942!		NOS			
	1	2	3	4	5
NOS 1	.001953	.001777	.002373	.004369	.001514
2	*	.050325	.005879	.010377	.003983
3	*	*	.071504	.017356	.005561
4	*	*	*	.135002	.011095
5	*	*	*	*	.046687

Table 5-6. Situation Matrix for Site S60E180.

VI. Conclusions

Results

The final measure of merit calculations were made for three different mission availability probabilities: .9172, .9626 and .9734. The results of the three evaluations produced identical orderings of locations for site selection. The major difference came from the measure of merit of the locations. The evaluation using the higher probability (.9626) provided the largest difference (over 7%) between the measure of merit of the best site (S60E180) and the last site (N20180). Using a lower probability (.8734) reduced the difference to 6.6%. Consequently, the more available the ground antenna at the site, the more important the selection of the site becomes.

The conclusions from the study were as expected. The four original ground antennas provided coverage mainly along the equator and in the northern hemisphere. The largest gap between the sites along the equator is from Kwajalein to Ascension. From this configuration, it follows that the area of least coverage should be in the southern hemisphere between these two sites. Table 6-1 lists the top 20 locations and their associated measure or merit (using .9172). From this list, 17 of the sites are south of the equator and the other three sites are on the equator between Kwajalein and Ascension. From the complete list in Appendix E, the first site selected above the equator (N20E244) is ranked number 35 and has a measure of merit of .900472, almost a four percent drop from the best selection.

	SITE	MEASURE OF MERIT	LOCAL LAND MASS
1.	S60E260	.939635	OCEAN
2.	S60E220	.939294	OCEAN
3.	S60E300	.939109	SOUTH SHETLAND IS
4.	S60E180	.93828	OCEAN
5.	S60E340	.93743	S. SANDWICH IS
6.	S40E258	.937424	OCEAN
7.	S40E232	.937156	OCEAN
8.	S60E140	.936637	OCEAN
9.	S20E223	.936148	ARCHPELAGO
10.	S40E206	.935989	OCEAN
11.	S40E180	.934657	N. ISLAND, NZ
12.	S20E244	.934388	OCEAN
13.	S20E265	.933981	OCEAN
14.	EQ0E240	.933913	OCEAN
15.	S20E201	.933761	COOK ISLANDS
16.	S40E294	.932815	CHILE
17.	S60E020	.931902	OCEAN
18.	S40E159	.931622	SE AUSTRALIA
19.	EQ0E220	.931394	OCEAN
20.	EQ0E260	.93098	OCEAN

Table 6-1. The Top 20 Locations for a Fifth Ground Antenna.

Generic Model

The model presented in this study can be easily manipulated to answer questions on other ground control configurations. If the user wanted to perform the same analysis without Cape Canaveral, then column 4 and row 4 of the situation matrix would be removed and the mission availability probability of Cape Canaveral would be set to one. This would effectively remove Cape Canvaveral from the analysis without drastically changing the model. The changing of the satellite constellation would be more tedious and would have to be done within the SATVIEW program, but the latter parts of this model would remain unchanged.

Conclusions

The final conclusions from this study are as follows:

1. The best location, based on this study, is at 20 degrees south latitude and 260 degrees east longitude.

2. The best location with a significant land mass nearby is at 60 degrees south latitude and 300 degrees east longitude, near the South Shetland Islands.

3. This model provided a smooth projection of the performance capability of the ground locations. The most feasible region appears to be the area of the southern Pacific Ocean.

4. The higher the mission availability of the ground antennas, the greater the importance of the results from this study for site selection.

Recommendation for Further Study

Clearly the positioning of the ground antenna in terms of strict availability is not a very sensitive aspect of the decision. And the performance model provides a definite picture of the best regions for placement of the fifth site. This study should be incorporated with further investigation into the economic, political and geographic considerations that might impact the site selection process.

APPENDIX A:

A LISTING OF THE ACTUAL POSITIONS OF THE 96 LOCATIONS

Appendix A

The following list represents the exact number used for input data of the 96 site locations in the SATVIEW program. The locations used are symmetrical about the equator so only the northern locations are listed here. The southern locations have the same longitudes but a southern latitude.

Site Designation	Latitude (N)	Longitude (E)
N60E180	60.0	180.0
N60E220		220.0
N60E260		260.0
N60E300		300.0
N60E340		340.0
N60E020		20.0
N60E060		60.0
N60E100		100.0
N60E140		140.0
N40E180	40.0	180.00
N40E206		206.11
N40E232		232.22
N40E258		258.32
N40E294		294.43
N40E311		310.55
N40E337		336.65
N40E003		2.76
N40E029		28.87
N40E055		54.97
N40E081		81.08
N40E107		107.19
N40E133		133.30
N40E159		159.41
N20E180	20.0	180.00
N20E180		201.28
N20E223		222.57
N20E244		243.85
N20E265		265.13
N20E286		286.42
N20E308		307.71
N20E329		328.92
N20E351		351.27
N20E012		11.55
N20E033		32.84

N20E054	20.0	54.12
N20E075		75.40
N20E097		96.69
N20E118		117.97
N20E139		139.25
EQ0E000	00.0	0.00
EQ0E020		20.00
EQ0E040		40.00
EQ0E060		60.00
EQ0E080		80.00
EQ0E100		100.00
EQ0E120		120.00
EQ0E140		140.00
EQ0E160		160.00
EQ0E180		180.00
EQ0E200		200.00
EQ0E220		220.00
EQ0E240		240.00
EQ0E260		260.00
EQ0E280		280.00
EQ0E300		300.00
EQ0E320		320.00
EQ0E340		340.00

APPENDIX B:

COMPUTER LISTING FOR GENERATING THE PERFORMANCE VALUES

Appendix B:

This program takes the information from the satellite viewing period data files (i.e. A1.DAT, A2.DAT, etc.) and computes the performance percentage for the specific situation. The program listed here computes for the situation of Kwajalein being non-operational. The output file (DCA5.dat) identifies the operational sites by its name (Diego Cape Ascension 5).

```
1       FULLW 2
2       DIM PRM1(1440)
3       DIM TMP1(1440)
4       XZ$ = "DCA5.DAT"
5       OPEN "O", #2, XZ$
6       FOR FILE = 1 TO 24
7       XS$ = "A1A2A3A4A5A6A7A8B1B2B3B4B5B6B7B8C1C2C3C4C5C6C7C8"
8       D = (FILE*2)-1
9       XX$ = MID$(XS$,D,2)
10      XY$ = XX$ + ".DAT"
12      OPEN "I", #1, XY$
20      '
21      '  INITIALIZE
22      '
32      FOR Z = 1 TO 1440
34      TMP1(Z) = 0
36      PRM1(Z) = 0
38      NEXT
40      INPUT#1, DAT$
41      '  BREAK UP INPUT STRING
42      GA$ = LEFT$(DAT$,7)
44      T$ = MID$(DAT$,39,6)
46      DUR$ = MID$(DAT$,86,3)
50      X = INSTR("KWAJALEASCENSIDIEGO GCAPE CA", GA$)
60      IF X = 0 THEN GOTO 200
61      '
62      '  DETERMINE START AND FINISH OF VIEW PERIODS
63      '
65      START = INT(VAL(T$)*60)
66      FINISH = INT(VAL(DUR$)) + START
67      '
68      '   DON'T INCLUDE KWAJALEIN IN GROUND NETWORK
69      '
70      IF X = 1 THEN GOTO 40
71      IF X = 8 THEN GOSUB 600 :GOTO 40
80      IF X = 15 THEN GOSUB 600 :GOTO 40
90      IF X = 22 THEN GOSUB 600 :GOTO 40
190     '
```

```
191   '   VIEW PERIODS OF PERMANENT GROUND NETWORK COMPLETE
192   '
200   GOSUB 490
250   TEST$ = GA$
255   '
256   '   INPUT VIEW PERIODS OF 96 TEST LOCATIONS
257   '
260   WHILE TEST$ = GA$
270   GOSUB 430
320   INPUT#1, DAT$
322   GA$ = LEFT$(DAT$,7)
324   T$ = MID$(DAT$,39,6)
326   DUR$ = MID$(DAT$,86,3)
327   IF EOF(1) = -1 THEN GOSUB 340 :GOTO 336
      : TEST$ = GA$ : GOSUB 490 : GOSUB 430 : GOTO 331
330   WEND
331   GOSUB 340
334   GOTO 220
336   CLOSE 1
337   NEXT
338   CLOSE 2
339   END
340   KNT1 = 0
345   '
346   '   COMPUTE PERFORMANCE PERCENTAGE FOR SITE
347   '
350   FOR N = 1 TO 1440
360   IF TMP1(N) = 1 THEN KNT1 = KNT1 + 1
370   NEXT
380   PC1! = KNT1/1440
390   TEST$ = XX$ + TEST$
395   '
396   '   PRINT TO OUTPUT FILE
397   '
400   PRINT#2, TEST$, PC1!
410   RETURN
430   START = INT(VAL(T$)*60)
440   FINISH = INT(VAL(DUR$)) + START
445   '
446   '   DETERMINE IMPACT OF FIFTH LOCATION
447   '
450   FOR J = START TO FINISH
460   TMP1(J) = 1
470   NEXT
480   RETURN
495   '
496   '   INITIALIZE GROUND NETWORK BEFORE EVALUATING 5TH SITE
497   '
490   FOR K = 1 TO 1440
500   TMP1(K) = PRM1(K)
510   NEXT
520   RETURN
595   '
596   '   DETERMINE PERMANENT GROUND NETWORK (DCA)
597   '
```

```
600    FOR I = START TO FINISH
610    PRM1(I) = 1
620    NEXT
630    RETURN
```

APPENDIX C:

A LISTING OF THE SITUATION BOXES FOR THE 96 SITES

Appendix C:

This appendix contains a list of the situation boxes for the 96 ground locations. The first line contains the number for box 1 and the site name, the following four lines contain the valuew for boxes 2-11. The values for boxes 12-16 are not included here because they are the same for all 96 locations and can be found in Table 5-5.

.990074	S60E180		
.91085	.874652	.777748	.757436
*	.953876	.782956	.731133
*	*	.902777	.814467
*	*	*	.901764

.990074	S60E220		
.901128	.874768	.738888	.76276
*	.963714	.776475	.767563
*	*	.889206	.810763
*	*	*	.911631

.990074	S60E260		
.879484	.863657	.699681	.741608
*	.974247	.789322	.801099
*	*	.882464	.807638
*	*	*	.915248

.990074	S60E300		
.854021	.84508	.674102	.703732
*	.981133	.818894	.815277
*	*	.886284	.806683
*	*	*	.910474

.989727	S60E340		
.834692	.827864	.670716	.668084
*	.982898	.856654	.799507
*	*	.900607	.807204
*	*	*	.896324

.983795	S60E020		
.827603	.820688	.692621	.651185
*	.97688	.878761	.761602
*	*	.912788	.809577
*	*	*	.880584

.978471	S60E60		
.837065	.825578	.729166	.658651
*	.966984	.87471	.723784
*	*	.91736	.812152
*	*	*	.873263
.981625	S60E100		
.866637	.833795	.768923	.688222
*	.948784	.83938	.702921
*	*	.919154	.813946
*	*	*	.876417
.990074	S60E140		
.902748	.861949	.795138	.727574
*	.949276	.808419	.706249
*	*	.917563	.81519
*	*	*	.887702
.990074	S40E180		
.93067	.856828	.793344	.78883
*	.916232	.707638	.68828
*	*	.891492	.8035
*	*	*	.902082
.990074	S40E206		
.922424	.865335	.743662	.801938
*	.932985	.701301	.730989
*	*	.869154	.795022
*	*	*	.915942
.990103	S40E232		
.904195	.867302	.694472	.79262
*	.953211	.705612	.780323
*	*	.853269	.788107
*	*	*	.924941
.990074	S40E258		
.876272	.856394	.650578	.762094
*	.970196	.721411	.821932
*	*	.84372	.781914
*	*	*	.928269
.985937	S40E294		
.828819	.820977	.604716	.695051
*	.978095	.762383	.846845
*	*	.84129	.774189
*	*	*	.918836

.984548	S40E311		
.810966	.804947	.593952	.664611
*	.978529	.786949	.844357
*	*	.84699	.772858
*	*	*	.910416
.970861	S40E337		
.787846	.783217	.590306	.621035
*	.966232	.81953	.809895
*	*	.852777	.759171
*	*	*	.877256
.952806	S40E003		
.769791	.765856	.606886	.592331
*	.948871	.851301	.760936
*	*	.869357	.765103
*	*	*	.848552
.94129	S40E029		
.761776	.756162	.637673	.583361
*	.935676	.868662	.714582
*	*	.884519	.779311
*	*	*	.836081
.937268	S40E055		
.771237	.751041	.681047	.592823
*	.917071	.855236	.671382
*	*	.88964	.784432
*	*	*	.832059
.943228	S40E081		
.801591	.746151	.729947	.623176
*	.887788	.812383	.641926
*	*	.89589	.790682
*	*	*	.83802
.953761	S40E107		
.84482	.768923	.775057	.666405
*	.877864	.7728	.632001
*	*	.901359	.796151
*	*	*	.848552
.970254	S40E133		
.894964	.808709	.811805	.71655
*	.883998	.740942	.638136
*	*	.906104	.800896
*	*	*	.865045

.988251	S40E159		
.929715	.844472	.821208	.763396
*	.903008	.720514	.661226
*	*	.90732	.806191
*	*	*	.887123
.932233	N40E180		
.876417	.788251	.71655	.826851
*	.844067	.608593	.655468
*	*	.807522	.759577
*	*	*	.884287
.930989	N40E206		
.871122	.782956	.670138	.851214
*	.842823	.591058	.6989
*	*	.789988	.77008
*	*	*	.911081
.930439	N40E232		
.848495	.760329	.620051	.838193
*	.842273	.582522	.748697
*	*	.781452	.771151
*	*	*	.920138
.931278	N40E258		
.800202	.712065	.571758	.795196
*	.843142	.58339	.797626
*	*	.782291	.777285
*	*	*	.926272
.937152	N40E294		
.75894	.682001	.540277	.73177
*	.860213	.621353	.838686
*	*	.797945	.785329
*	*	*	.924536
.937152	N40E311		
.754137	.683159	.54563	.702545
*	.866174	.651359	.837441
*	*	.808101	.789148
*	*	*	.918199
.938685	N40E337		
.757464	.690798	.570601	.663599
*	.872019	.700201	.819849
*	*	.831133	.797482
*	*	*	.905034

.938714	N40E003		
.76545	.697626	.606365	.640306
*	.87089	.734548	.782464
*	*	.852661	.799825
*	*	*	.882582

.938685	N40E029		
.77931	.706741	.650202	.632696
*	.866116	.749883	.733188
*	*	.866781	.793373
*	*	*	.862805

.938685	N40E055		
.797482	.718865	.696729	.640045
*	.860068	.74942	.688193
*	*	.876417	.789264
*	*	*	.84961

.938685	N40E081		
.818373	.735908	.736602	.662557
*	.85622	.733766	.652459
*	*	.879658	.783564
*	*	*	.841027

.938685	N40E107		
.843141	.758361	.765942	.701301
*	.853905	.705844	.629802
*	*	.876764	.77824
*	*	*	.838694

.938685	N40E133		
.863743	.776591	.774102	.749189
*	.851533	.669791	.622453
*	*	.863252	.773466
*	*	*	.847138

.936486	N40E159		
.87578	.787615	.750144	.792939
*	.848321	.633246	.633593
*	*	.832175	.758101
*	*	*	.860971

.938714	N60E180		
.857406	.771006	.710763	.817302
*	.852314	.638743	.713454
*	*	.8342	.800665
*	*	*	.905178

.938685	N60E220		
.848436	.76221	.670167	.824768
*	.852458	.625462	.751099
*	*	.821729	.800665
*	*	*	.917621
.938685	N60E260		
.822713	.738656	.630583	.800115
*	.854629	.629368	.788598
*	*	.819675	.80162
*	*	*	.92063
.938685	N60E300		
.798986	.718894	.613078	.759461
*	.858593	.655439	.804108
*	*	.827545	.804687
*	*	*	.915827
.938685	N60E340		
.792563	.715913	.625462	.724565
*	.862036	.690884	.791318
*	*	.841782	.807783
*	*	*	.904686
.938685	N60E020		
.798668	.72118	.658708	.707927
*	.861197	.713106	.758448
*	*	.855931	.808419
*	*	*	.891174
.938685	N60E60		
.813367	.732551	.6978	.713946
*	.857869	.715161	.721324
*	*	.864814	.807378
*	*	*	.881249
.938685	N60E100		
.832956	.749652	.728124	.741926
*	.855381	.696585	.697308
*	*	.864438	.805612
*	*	*	.87986
.938685	N60E140		
.850317	.765161	.734027	.782609
*	.853529	.666029	.693749
*	*	.852603	.802632
*	*	*	.888714

.982146	S20E180		
.943894	.855728	.787644	.8171
*	.89398	.65949	.662644
*	*	.858419	.767736
*	*	*	.891463

.990074	S20E201		
.942331	.859548	.746035	.846845
*	.907291	.65622	.7035
*	*	.849768	.782204
*	*	*	.922511

.990074	S20E223		
.924883	.856278	.698234	.843257
*	.921469	.662036	.751562
*	*	.841405	.787296
*	*	*	.935966

.986255	S20E244		
.881394	.829542	.65295	.802719
*	.934403	.674652	.797569
*	*	.837268	.790653
*	*	*	.93964

.984316	S20E265		
.842158	.811805	.613714	.756538
*	.953963	.694212	.844617
*	*	.835329	.792071
*	*	*	.941058

.980207	S20E286		
.811631	.803066	.583188	.708853
*	.971642	.718836	.879282
*	*	.83122	.785271
*	*	*	.934258

.967215	S20E308		
.784866	.776562	.556423	.654426
*	.958911	.738656	.867765
*	*	.818228	.760532
*	*	*	.909519

.952661	S20E329		
.769646	.766492	.542823	.611602
*	.949507	.76982	.8364
*	*	.805294	.720456
*	*	*	.867823

.937412	S20E351		
.754397	.752603	.54699	.576475
*	.935618	.795398	.788859
*	*	.809461	.704744
*	*	*	.832696
.929455	S20E012		
.74644	.740392	.582551	.568026
*	.923408	.838512	.741897
*	*	.845022	.739814
*	*	*	.824247
.929455	S20E033		
.74644	.725578	.631828	.568026
*	.908593	.86655	.692245
*	*	.887615	.782406
*	*	*	.824247
.930873	S20E054		
.747974	.705902	.680931	.569559
*	.888801	.859374	.645601
*	*	.902574	.797366
*	*	*	.825665
.934056	S20E075		
.76681	.691261	.728066	.588396
*	.858506	.819009	.612644
*	*	.906481	.801272
*	*	*	.828847
.936168	S20E097		
.808159	.72008	.772163	.629744
*	.848089	.77199	.602227
*	*	.903934	.798726
*	*	*	.83096
.941261	S20E118		
.85732	.769154	.810908	.678905
*	.853095	.727719	.607233
*	*	.898263	.793055
*	*	*	.836052
.951098	S20E139		
.907349	.819183	.839062	.728934
*	.862933	.690422	.617071
*	*	.889148	.78394
*	*	*	.84589

.931133	N20E180		
.907638	.819472	.732464	.835474
*	.842968	.585097	.63015
*	*	.784027	.711862
*	*	*	.858969
.935098	N20E201		
.904108	.815942	.690971	.874131
*	.846932	.587181	.676301
*	*	.78611	.756133
*	*	*	.905121
.940277	N20E223		
.874392	.786226	.645948	.864582
*	.852111	.59236	.72633
*	*	.79129	.78148
*	*	*	.930468
.943431	N20E244		
.828356	.740219	.599912	.823147
*	.855294	.595543	.774941
*	*	.794443	.789235
*	*	*	.938222
.941521	N20E265		
.780815	.696064	.552372	.775433
*	.85677	.597019	.821498
*	*	.792534	.787586
*	*	*	.936573
.934287	N20E286		
.751417	.685068	.522974	.728847
*	.867939	.608188	.863859
*	*	.7853	.782985
*	*	*	.931972
.933824	N20E308		
.750809	.703529	.522858	.687354
*	.886544	.646614	.878442
*	*	.785329	.777227
*	*	*	.925722
.937152	N20E329		
.754137	.708535	.535734	.647627
*	.89155	.693141	.855555
*	*	.798205	.764901
*	*	*	.903847

.937152	N20E351		
.754137	.7046	.562991	.614409
*	.887615	.739814	.804339
*	*	.825462	.75894
*	*	*	.87063
.938252	N20E012		
.755236	.699015	.598668	.597569
*	.88203	.780844	.757783
*	*	.861139	.776677
*	*	*	.85379
.938685	N20E033		
.761197	.696353	.644444	.593141
*	.873842	.795398	.710097
*	*	.881972	.787123
*	*	*	.843836
.938685	N20E054		
.773842	.69916	.69346	.601185
*	.864004	.79181	.666666
*	*	.893315	.793865
*	*	*	.839235
.938685	N20E075		
.795919	.713512	.741666	.622453
*	.856278	.774594	.632696
*	*	.898755	.798494
*	*	*	.838425
.938685	N20E097		
.832204	.7467	.787325	.659374
*	.853182	.744733	.612181
*	*	.899305	.797279
*	*	*	.83666
.93585	N20E118		
.862875	.77471	.81383	.699565
*	.847684	.700317	.601822
*	*	.889235	.784027
*	*	*	.830641
.931365	N20E139		
.882753	.794588	.798986	.744328
*	.843199	.650636	.597337
*	*	.849565	.744357
*	*	*	.826156

.936081	EQ0E000		
.753066	.735387	.556596	.58339
*	.918402	.800693	.798379
*	*	.819067	.722598
*	*	*	.839611

.937152	EQ0E020		
.754137	.723263	.613657	.580728
*	.906278	.845254	.745456
*	*	.876128	.775925
*	*	*	.836949

.937181	EQ0E040		
.754166	.705786	.667881	.58067
*	.888801	.863338	.687904
*	*	.911718	.811428
*	*	*	.836891

.938714	EQ0E060		
.757406	.68585	.722048	.581394
*	.867158	.856104	.63556
*	*	.928674	.825867
*	*	*	.835907

.935966	EQ0E080		
.780757	.693228	.777777	.602343
*	.848437	.822945	.602574
*	*	.933651	.828442
*	*	*	.830757

.933448	EQ0E100		
.826619	.738454	.822048	.648205
*	.845283	.770804	.59942
*	*	.928876	.823668
*	*	*	.82824

.935705	EQ0E120		
.88096	.792794	.85379	.702545
*	.84754	.71901	.601677
*	*	.908535	.803327
*	*	*	.830497

.937615	EQ0E140		
.923321	.835155	.852053	.759576
*	.849449	.667418	.603587
*	*	.866347	.761139
*	*	*	.832406

.944009	EQ0E160		
.940711	.852545	.81464	.809692
*	.855844	.620456	.609982
*	*	.819386	.714177
*	*	*	.838801
.961255	EQ0E180		
.951446	.86328	.777893	.858101
*	.873089	.615277	.641087
*	*	.814206	.722858
*	*	*	.869906
.971903	EQ0E200		
.949594	.861428	.738251	.899739
*	.883737	.623986	.693228
*	*	.822916	.773061
*	*	*	.922048
.980873	EQ0E220		
.919993	.832956	.69155	.891318
*	.893836	.634085	.745514
*	*	.831886	.803211
*	*	*	.952198
.981596	EQ0E240		
.873668	.796209	.645225	.85188
*	.904137	.644386	.796758
*	*	.832609	.815769
*	*	*	.964756
.97633	EQ0E260		
.829253	.769212	.600809	.803992
*	.916289	.656538	.849941
*	*	.827343	.817794
*	*	*	.966781
.967736	EQ0E280		
.793749	.757638	.565306	.750983
*	.931625	.671874	.894993
*	*	.818749	.812817
*	*	*	.961805
.95324	EQ0E300		
.770225	.759403	.541782	.697655
*	.942418	.690884	.92063
*	*	.804253	.793141
*	*	*	.942129

.938136	EQ0E320		
.755121	.753587	.526677	.644964
*	.936602	.72199	.898842
*	*	.789148	.752198
*	*	*	.901569

.932668	EQ0E340		
.749758	.743568	.523399	.59855
*	.926449	.753109	.835174
*	*	.788254	.706279
*	*	*	.853332

APPENDIX D:

COMPUTER CODE FOR MERIT CALCULATIONS

Appendix D:

The following computer code performs the necessary calculations for determining the final measure of merit for each of the 96 ground antenna locations. The results are printed out by descending order of merit with the site name followed by the merit figure.

```
10      FULLW 2
20      '
30      '  THIS PROGRAM CALCULATES THE MEASURE OF MERIT OF 96
32      '  GROUND ANTENNA LOCATIONS AND WRITES THEM TO A FILE
34      '  IN DESCENDING ORDER.
40      '
50      DIM LOC$(96), PFM!(16), PCELL!(16), SUM!(96), PMA!(5)
60      '
65      '  OPEN FILES FOR INPUT AND OUTPUT
70      '
80      OPEN "I", #1, "PRMNC.DAT"
90      OPEN "O", #2, "FINAL2.DAT"
100     '
110     '   INITIALIZE THE PROBABILITY OF MISSION AVAILABILITY
115     '   FOR EACH OF THE GROUND ANTENNAS
120     '
130     PMA!(1) = .9629
140     PMA!(2) = .9134
150     PMA!(3) = .8754
160     PMA!(4) = .7880
170     PMA!(5) = .9172
180     '
190     '   PERFORMANCE #'S ARE CONSTANT FOR BOXES 12-16
200     '
210     PFM!(12) = .780469
220     PFM!(13) = .836690
230     PFM!(14) = .777749
240     PFM!(15) = .820949
250     PFM!(16) = .929456
260     '
270     '   CALCULATE THE PROBABILITY OF EACH SITUATION (I.E.,
275     '   PCELL!(1) IS THE PROBABILITY ALL 5 SITES UP)
280     '
290     PCELL!(1) = PMA!(1)*PMA!(2)*PMA!(3)*PMA!(4)*PMA!(5)
300     PCELL!(2) = (1-PMA!(1))*PMA!(2)*PMA!(3)*PMA!(4)*PMA!(5)
310     PCELL!(3) = (1-PMA!(1))*(1-PMA!(2))*PMA!(3)*PMA!(4)*PMA!(5)
320     PCELL!(4) = PMA!(1)*(1-PMA!(2))*PMA!(3)*PMA!(4)*PMA!(5)
330     PCELL!(5) = (1-PMA!(1))*PMA!(2)*(1-PMA!(3))*PMA!(4)*PMA!(5)
340     PCELL!(6) = PMA!(1)*(1-PMA!(2))*(1-PMA!(3))*PMA!(4)*PMA!(5)
350     PCELL!(7) = PMA!(1)*PMA!(2)*(1-PMA!(3))*PMA!(4)*PMA!(5)
```

```
360   PCELL!(8) = (1-PMA!(1))*PMA!(2)*PMA!(3)*(1-PMA!(4))*PMA!(5)
370   PCELL!(9) = PMA!(1)*(1-PMA!(2))*PMA!(3)*(1-PMA!(4))*PMA!(5)
380   PCELL!(10) = PMA!(1)*PMA!(2)*(1-PMA!(3))*(1-PMA!(4))*PMA!(5)
390   PCELL!(11) = PMA!(1)*PMA!(2)*PMA!(3)*(1-PMA!(4))*PMA!(5)
400   PCELL!(12) = (1-PMA!(1))*PMA!(2)*PMA!(3)*PMA!(4)*(1-PMA!(5))
410   PCELL!(13) = PMA!(1)*(1-PMA!(2))*PMA!(3)*PMA!(4)*(1-PMA!(5))
420   PCELL!(14) = PMA!(1)*PMA!(2)*(1-PMA!(3))*PMA!(4)*(1-PMA!(5))
430   PCELL!(15) = PMA!(1)*PMA!(2)*PMA!(3)*(1-PMA!(4))*(1-PMA!(5))
440   PCELL!(16) = PMA!(1)*PMA!(2)*PMA!(3)*PMA!(4)*(1-PMA!(5))
450   '
460   '   #'S FOR BOXES 12-16 CONSTANT
470   '
480   BOX12! = PFM!(12)*PCELL!(12)
490   BOX13! = PFM!(13)*PCELL!(13)
500   BOX14! = PFM!(14)*PCELL!(14)
510   BOX15! = PFM!(15)*PCELL!(15)
520   BOX16! = PFM!(16)*PCELL!(16)
530   '
540   '   INITIALIZE ARRAYS
550   '
560   CONST! = BOX12! + BOX13! + BOX14! + BOX15! + BOX16!
570   FOR J = 1 TO 96
580   SUM!(J) = CONST!
590   LOC$(J) = ""
600   NEXT
610   '
620   '   INPUT DATA ONE LINE AT A TIME
630   '
640   INPUT#1, DAT$
650   '
660   '   GET INFO FROM DATA LINE
670   '
680   CELL$ = LEFT$(DAT$,1)
690   SITE$ = MID$(DAT$,2,7)
700   NUM$  = MID$(DAT$,23,8)
710   '
720   '   DETERMINE BOX NUMBER
730   '
740   IF CELL$ = "A" THEN BOX = 10 :GOTO 800
750   IF CELL$ = "B" THEN BOX = 11 :GOTO 800
760   BOX = INT(VAL(CELL$))
770   '
780   '   INITIALIZE LOOPING VARIABLES
790   '
800   TRUE = 1
810   I = 1
```

```
820   '
830   '   DETERMINE WHICH SITE IS BEING EVALUATED
840   '
850   WHILE TRUE = 1
860   IF LEN(LOC$(I)) = 0 THEN LOC$(I) = SITE$ :GOSUB 1240 :GOTO 890
870   IF SITE$ = LOC$(I) THEN GOSUB 1240 :GOTO 890
880   I = I + 1
890   WEND
900   '
910   '   CHECK FOR END OF FILE
920   '
930   IF EOF(1) = -1 THEN GOTO 980
940   GOTO 640
950   '
960   '   PERFORM SORT ROUTINE
970   '
980   FOR N = 1 TO 95
990   R = N
1000  FOR M = (N+1) TO 96
1010  IF SUM!(M) > SUM!(R) THEN R = M
1020  NEXT
1030  '
1040  '  SWAP LOCATIONS WITHIN ARRAY
1050  '
1060  TMP$ = LOC$(N) : TMP! = SUM!(N)
1070  LOC$(N) = LOC$(R) :SUM!(N) = SUM!(R)
1080  LOC$(R) = TMP$ : SUM!(R) = TMP!
1090  NEXT
1100  '
1110  '    WRITE TO DATA FILE
1120  '
1130  FOR P = 1 TO 96
1140  PRINT#2, LOC$(P), SUM!(P)
1150  NEXT
1160  '
1170  '    CLOSE FILES
1180  '
1190  CLOSE 1,2
1200  END
1210  '
1220  '    CALCULATE MEASURE OF MERIT
1230  '
1240  PC! = VAL(NUM$)
1250  PRFM! = PCELL!(BOX) * PC!
1260  SUM!(I) = SUM!(I) + PRFM!
1270  TRUE = 2
1280  RETURN
```

APPENDIX E:

Measures of Merit for the 96 Site Locations

Appendix E:

This appendix contains a listing of the ground sites in descending order of measure of merit. This list was produced by using a mission availability probability of .9172.

S60E260	.939635
S60E220	.939294
S60E300	.939109
S60E180	.93828
S60E340	.93743
S40E258	.937424
S40E232	.937156
S60E140	.936637
S20E223	.936148
S40E206	.935989
S40E180	.934657
S20E244	.934388
S20E265	.933981
EQ0E240	.933913
S20E201	.933761
S40E294	.932815
S60E020	.931902
S40E159	.931622
EQ0E220	.931394
EQ0E260	.93098
S20E286	.930776
S40E311	.930753
S60E100	.929367
S60E60	.927538
EQ0E280	.925031
S20E180	.923801
EQ0E200	.920069
S40E337	.916643
S20E308	.916576
S40E133	.915799
EQ0E300	.912647
EQ0E180	.903135
S40E107	.901946
S40E003	.901829
N20E244	.900472
S20E139	.899219
S20E329	.899014
N20E265	.898196
N20E223	.897719
N60E260	.897709
N60E220	.897587

N60E300	.897467
N60E340	.896951
N60E180	.896577
N60E020	.895866
N40E337	.89562
N60E140	.895292
EQ0E320	.895033
N60E60	.894867
N60E100	.894688
N40E311	.894372
N40E294	.894165
N40E003	.893857
S40E029	.893684
S40E081	.89356
N20E286	.893074
N20E308	.893022
N20E329	.892537
EQ0E060	.891892
N40E029	.89143
EQ0E040	.891277
S20E118	.891261
S40E055	.890042
N20E201	.88996
N40E055	.889768
N20E012	.889567
N20E097	.889525
N20E033	.889427
N40E258	.889385
N20E075	.889252
EQ0E020	.889167
EQ0E080	.889143
N20E054	.889091
N20E351	.888895
EQ0E120	.888755
N40E232	.888584
N40E081	.888525
N40E133	.888441
N40E206	.888333
N40E107	.888069
EQ0E100	.887757
EQ0E160	.887375
EQ0E140	.886921
S20E097	.886676
N40E159	.886673
N20E118	.886223
N40E180	.885885
S20E075	.885173
S20E054	.884275
EQ0E000	.884213
S20E351	.883504
S20E033	.883379
EQ0E340	.882101

S20E012	.880253
N20E139	.879074
N20E180	.878842

This list was produced using a mission availability probability of .9626.

S60E260	.945026
S60E220	.944668
S60E300	.944474
S60E180	.943603
S60E340	.942712
S40E258	.942705
S40E232	.942424
S60E140	.941879
S20E223	.941365
S40E206	.941199
S40E180	.9398
S20E244	.939518
S20E265	.939091
EQ0E240	.939019
S20E201	.938859
S40E294	.937866
S60E020	.936908
S40E159	.936614
EQ0E220	.936375
EQ0E260	.93594
S20E286	.935725
S40E311	.935701
S60E100	.934246
S60E60	.932326
EQ0E280	.929694
S20E180	.928404
EQ0E200	.924485
S40E337	.920889
S20E308	.920819
S40E133	.920002
EQ0E300	.916694
EQ0E180	.906707
S40E107	.905459
S40E003	.905336
N20E244	.903912
S20E139	.902596
S20E329	.902381
N20E265	.901523
N20E223	.901022
N60E260	.901011
N60E220	.900883
N60E300	.900757
N60E340	.900216
N60E180	.899823
N60E020	.899076
N40E337	.898818
N60E140	.898473
EQ0E320	.898202
N60E60	.898027
N60E100	.89784

N40E311	.897508
N40E294	.897291
N40E003	.896967
S40E029	.896786
S40E081	.896655
N20E286	.896145
N20E308	.896091
N20E329	.895582
EQ0E060	.894905
N40E029	.89442
EQ0E040	.894258
S20E118	.894242
S40E055	.892962
N20E201	.892876
N40E055	.892674
N20E012	.892463
N20E097	.892419
N20E033	.892316
N40E258	.892272
N20E075	.892133
EQ0E020	.892043
EQ0E080	.892018
N20E054	.891963
N20E351	.891758
EQ0E120	.891611
N40E232	.891432
N40E081	.891369
N40E133	.891281
N40E206	.891168
N40E107	.890891
EQ0E100	.890563
EQ0E160	.890162
EQ0E140	.889686
S20E097	.889428
N40E159	.889426
N20E118	.888952
N40E180	.888598
S20E075	.88785
S20E054	.886908
EQ0E000	.886842
S20E351	.886099
S20E033	.885967
EQ0E340	.884625
S20E012	.882686
N20E139	.881448
N20E180	.881204

This list was produced using a mission availability probability of .8754.

S60E260	.934704
S60E220	.934379
S60E300	.934202
S60E180	.93341
S60E340	.9326
S40E258	.932594
S40E232	.932338
S60E140	.931843
S20E223	.931376
S40E206	.931224
S40E180	.929953
S20E244	.929696
S20E265	.929308
EQ0E240	.929242
S20E201	.929097
S40E294	.928194
S60E020	.927323
S40E159	.927056
EQ0E220	.926839
EQ0E260	.926443
S20E286	.926248
S40E311	.926226
S60E100	.924903
S60E60	.923158
EQ0E280	.920765
S20E180	.919592
EQ0E200	.916029
S40E337	.91276
S20E308	.912696
S40E133	.911954
EQ0E300	.908946
EQ0E180	.899867
S40E107	.898732
S40E003	.898621
N20E244	.897326
S20E139	.896129
S20E329	.895934
N20E265	.895154
N20E223	.894698
N60E260	.894688
N60E220	.894572
N60E300	.894457
N60E340	.893966
N60E180	.893608
N60E020	.892929
N40E337	.892694
N60E140	.892382
EQ0E320	.892135
N60E60	.891976
N60E100	.891806

N40E311	.891504
N40E294	.891306
N40E003	.891012
S40E029	.890847
S40E081	.890728
N20E286	.890265
N20E308	.890215
N20E329	.889752
EQ0E060	.889137
N40E029	.888696
EQ0E040	.88855
S20E118	.888534
S40E055	.887371
N20E201	.887293
N40E055	.88711
N20E012	.886917
N20E097	.886877
N20E033	.886784
N40E258	.886744
N20E075	.886617
EQ0E020	.886536
EQ0E080	.886513
N20E054	.886463
N20E351	.886277
EQ0E120	.886142
N40E232	.88598
N40E081	.885923
N40E133	.885843
N40E206	.88574
N40E107	.885488
EQ0E100	.88519
EQ0E160	.884826
EQ0E140	.884392
S20E097	.884158
N40E159	.884156
N20E118	.883726
N40E180	.883404
S20E075	.882724
S20E054	.881867
EQ0E000	.881807
S20E351	.881131
S20E033	.881011
EQ0E340	.879792
S20E012	.878028
N20E139	.876903
N20E180	.876682

Bibliography

1. Alford, Major Dennis L. History of the NAVSTAR Global Positioning System (1963-1985). ACSC/EDCC, Maxwell AFB, AL. April 1986.

2. Bate, Roger R. and et al. Fundamental of Astrodynamics. New York: Dover Publications, Inc., 1971.

3. Bone, Russell P. Chief of Logistics. Personal Interview. Joint Service Systems Management Office (JSSMO) for the GPS NAVSTAR, Warner Robins AFB, GA. November 1987.

4. Elrod, B. D. and A. Weinberg. "Satellite-Aided ATC System Concepts Employing the NAVSTAR Global Positioning System." NAVIGATION. Volume 25 Number 2. Summer 1978.

5. GPS Weekly OCS Reports. Second Satellite Control Squadron, Falcon Air Force Station, CO. August-November 1987.

6. Kalafus, R. M. Reliability of Navigation Service Provided by the Global Positioning System. U.S. Department of Transportation. DOT/FAA/ES-85/4. May 1985 (AD-A163541).

7. McDowell, Donald M. Chief of Engineers. Personal Correspondence. JSSMO for the GPS NAVSTAR, Warner Robins AFB, GA. September-November 1987.

8. Milliken R. J. and C. J. Zoeller. "Principle of Operation of NAVSTAR and System Characteristics." NAVIGATION. Volume 25 Number 2. Summer 1978.

9. Satellite Analysis Program Library - Program Module Description. General Research Corporation. Report Number CR1-1363. February 1986.

10. Spilker, J.J. "GPS Signal Structure and Performance Characteristics." NAVIGATION. Volume 25 Number 2. Summer 1978.

11. Straits, Raymond J., Jr. A Current Review of the Global Positioning System. Report Number RG-84-3. October 1983 (AD-B080647).

12. System Specification for the Operational Control System Segment of the NAVSTAR Global Positioning System. IBM Corporation. Contract Number F04701-80-C-0011. June 6, 1986.

13. Van Leeuwen, A. et al. "The Global Positioning System and Its Application in Spacecraft Navigation." NAVIGATION. Volume 25 Number 2. Summer 1978.

14. Watkins, Warren Seki. Command and Control Functions and Organizational Structure Required to Support the NAVSTAR Global Positioning System. Masters Thesis. Naval Postgraduate School, Monterey, CA. June 1980 (AD-B051422).

VITA

Captain Tery L. Donelson was born on 1 May 1957 in Margate, England. He graduated from high school in Atwater, California, in 1975 and attended California State Polytechnic University of Pomona, from which he received the degree of Bachelor of Science in Computer Science in March 1982. Upon graduation, he received a commission in the USAF through the ROTC program. He was assigned to the Air Force Data Services Center, at the Pentagon, where he served as a computer programmer until March 1983. He then served as the Officer-in-Charge of the Air Force Drill Team and the Officer-in-Charge of the Honor Guard Ceremonial Flight for the USAF Honor Guard in Washington D.C. until entering the School of Engineering, Air Force Institute of Technology, in June 1986.

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